

(12) **United States Patent**
Lin et al.

(10) **Patent No.:** **US 9,263,392 B1**
(45) **Date of Patent:** **Feb. 16, 2016**

(54) **SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/529,129**

(22) Filed: **Oct. 30, 2014**

(30) **Foreign Application Priority Data**

Sep. 17, 2014 (CN) 2014 1 0474214

(51) **Int. Cl.**
H01L 21/336 (2006.01)
H01L 23/535 (2006.01)
H01L 29/78 (2006.01)
H01L 21/8234 (2006.01)
H01L 21/768 (2006.01)

H01L 21/02 (2006.01)
H01L 21/311 (2006.01)
(52) **U.S. Cl.**
CPC **H01L 23/535** (2013.01); **H01L 21/0217** (2013.01); **H01L 21/31144** (2013.01); **H01L 21/76802** (2013.01); **H01L 21/76877** (2013.01); **H01L 21/823475** (2013.01); **H01L 29/78** (2013.01)

(58) **Field of Classification Search**
CPC H01L 29/49
USPC 438/19–217
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,536,040	B1	9/2013	Park	
8,741,717	B2	6/2014	Hoon	
2005/0277258	A1 *	12/2005	Huang et al.	438/300
2007/0099414	A1 *	5/2007	Frohberg et al.	438/618
2013/0320412	A1	12/2013	Yamasaki	
2014/0273386	A1 *	9/2014	Tsao et al.	438/301

* cited by examiner

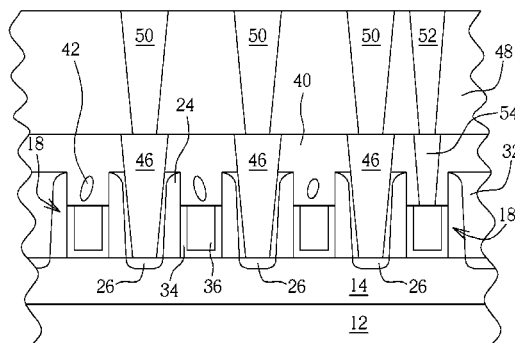
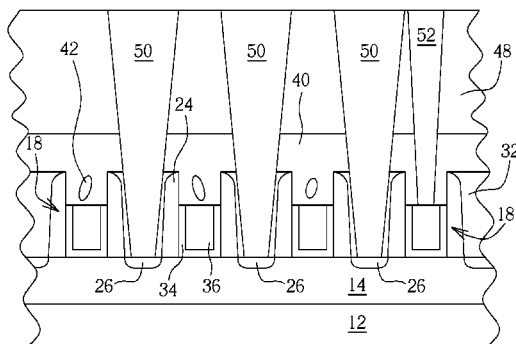
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(57) **ABSTRACT**

A method for fabricating semiconductor device is disclosed. The method includes the steps of: providing a substrate having a metal gate thereon and an interlayer dielectric (ILD) layer around the metal gate; removing part of the metal gate to form a recess; and depositing a mask layer in the recess and on the ILD layer while forming a void in the recess.

24 Claims, 4 Drawing Sheets



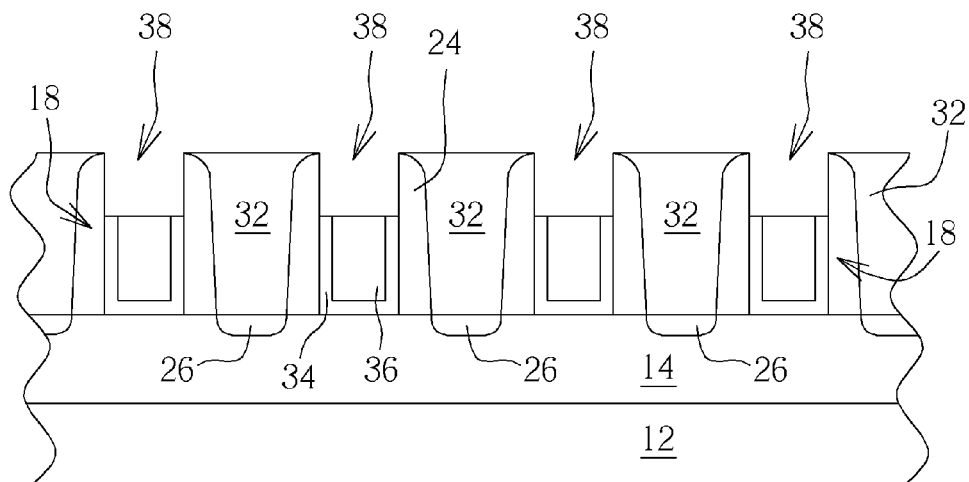


FIG. 1

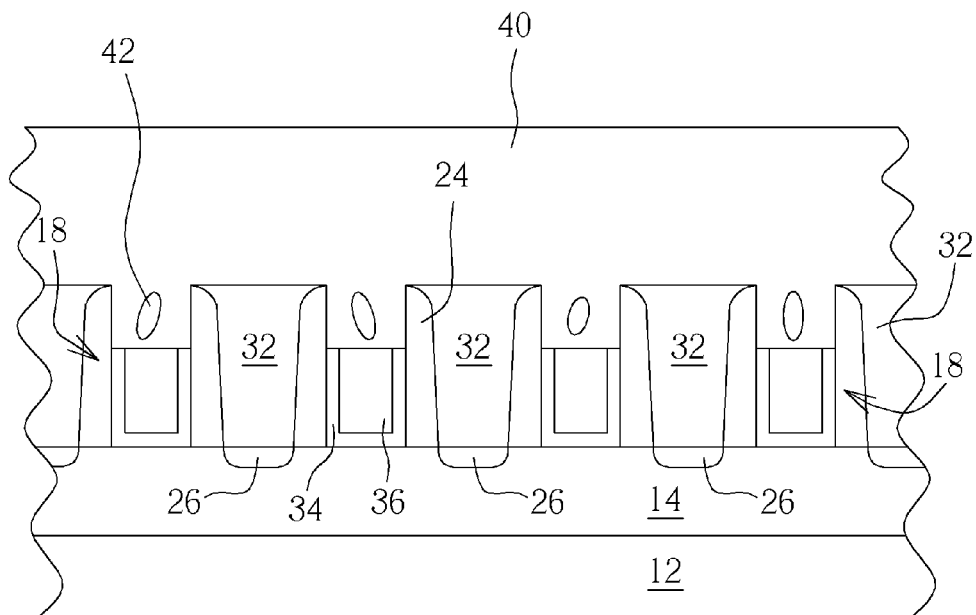


FIG. 2

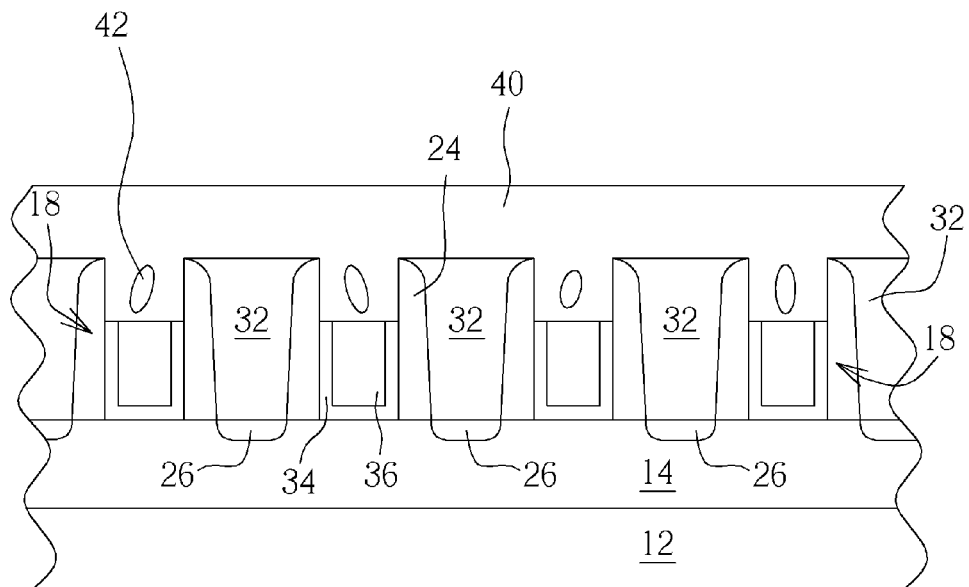


FIG. 3

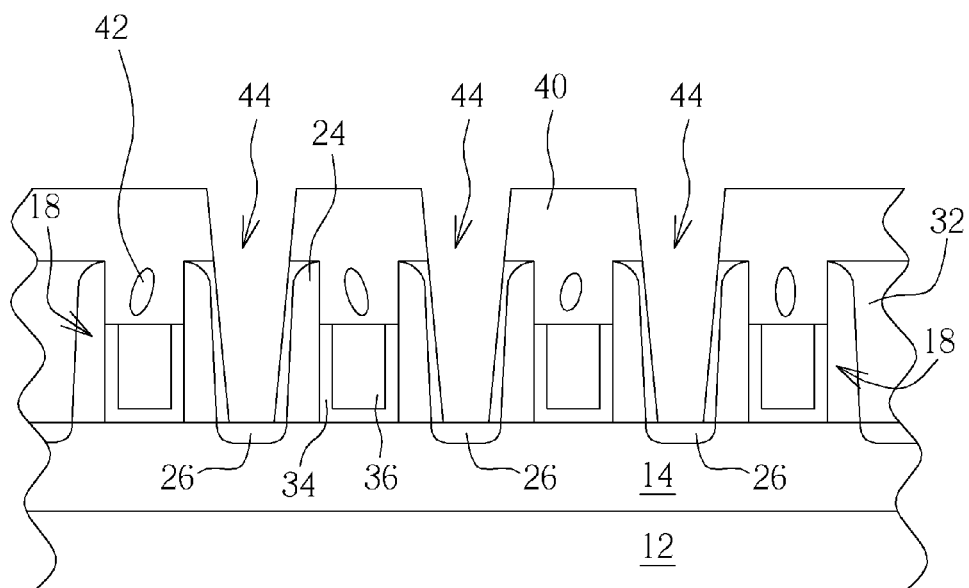


FIG. 4

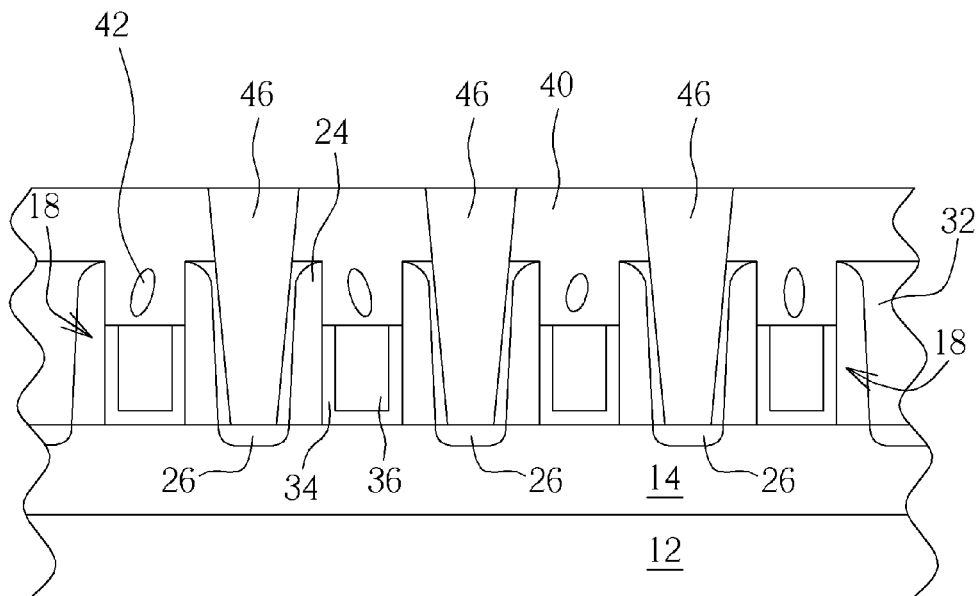


FIG. 5

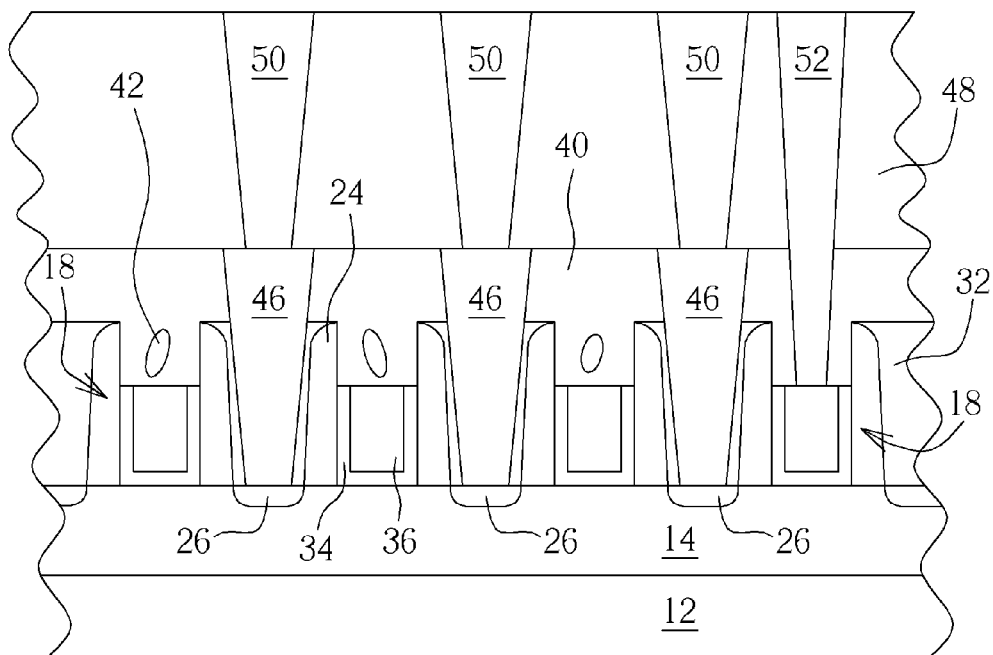


FIG. 6

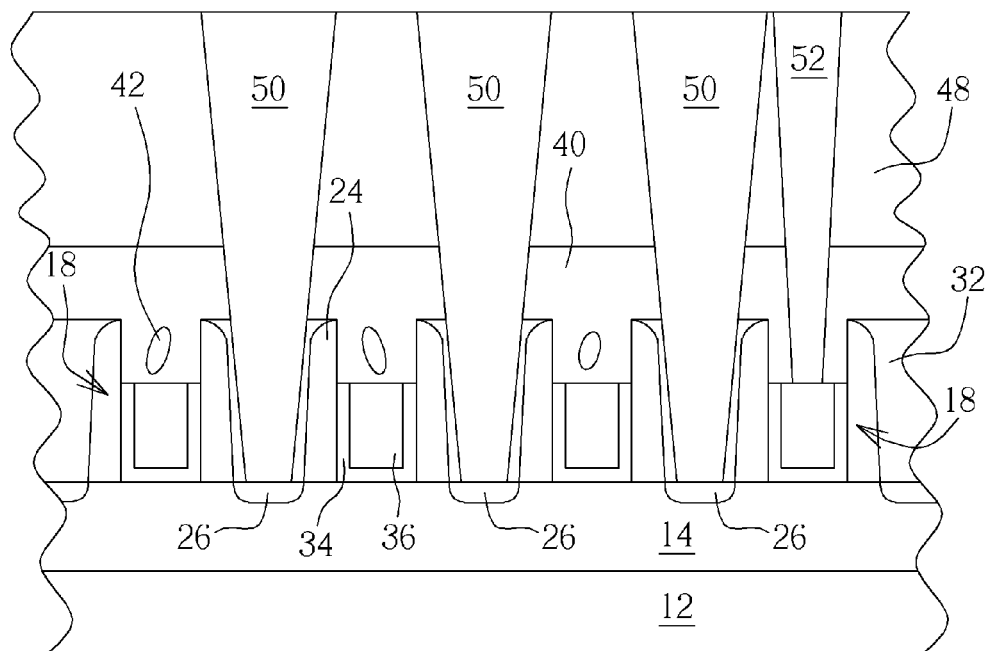


FIG. 7

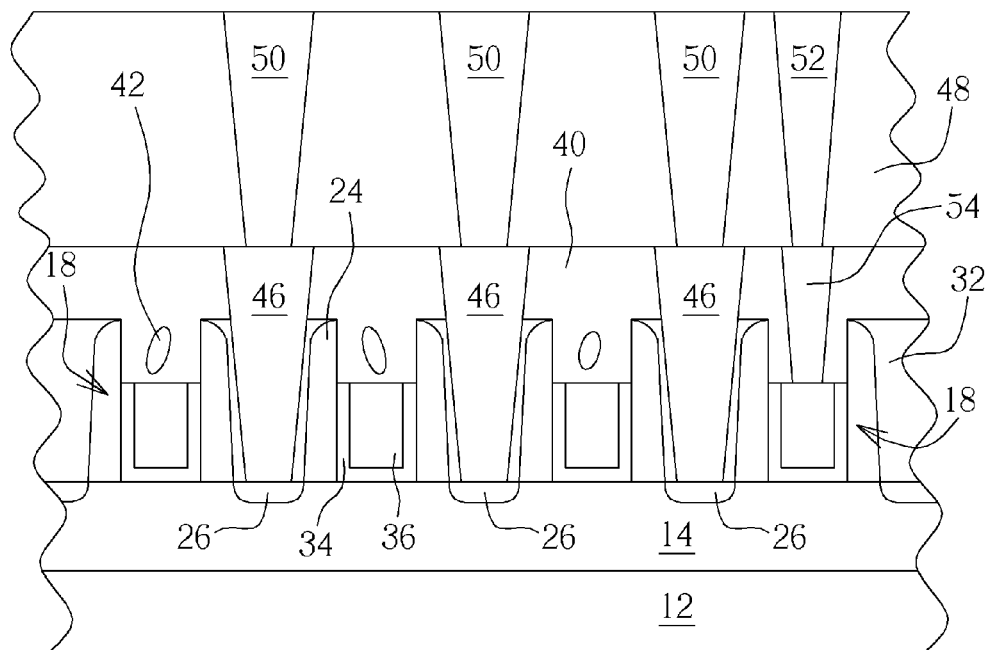


FIG. 8

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SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a method for fabricating semiconductor device, and more particularly, to a metal gate process.

2. Description of the Prior Art

In current semiconductor industry, polysilicon has been widely used as a gap-filling material for fabricating gate electrode of metal-oxide-semiconductor (MOS) transistors. However, the conventional polysilicon gate also faced problems such as inferior performance due to boron penetration and unavoidable depletion effect which increases equivalent thickness of gate dielectric layer, reduces gate capacitance, and worsens driving force of the devices. In replacing polysilicon gates, work function metals have been developed to serve as a control electrode working in conjunction with high-K gate dielectric layers.

However, in current fabrication of high-k metal transistor, particularly during the stage for fabricating self-aligned contacts (SAC), part of the metal gates are typically removed and a protective mask layer is formed on the metal gates. The deposited protective mask layer is then planarized through chemical mechanical polishing (CMP) process so that the surface of the remaining mask layer is even with the surface of the interlayer dielectric (ILD) layer. This design however causes contact plugs formed thereafter to be too close to the metal gates thereby affecting performance of the device. Hence, how to improve the current process for fabricating metal gates for resolving this issue has become an important task in this field.

SUMMARY OF THE INVENTION

According to a preferred embodiment of the present invention, a method for fabricating semiconductor device is disclosed. The method includes the steps of: providing a substrate having a metal gate thereon and an interlayer dielectric (ILD) layer around the metal gate; removing part of the metal gate to form a recess; and depositing a mask layer in the recess and on the ILD layer while forming a void in the recess.

According to another aspect of the present invention, a method for fabricating semiconductor device is disclosed. The method includes the steps of: providing a substrate having a metal gate thereon and an interlayer dielectric (ILD) layer around the metal gate; removing part of the metal gate to form a recess; depositing a mask layer in the recess and on the ILD layer; and performing a planarizing process to remove part of the mask layer so that the top surface of the remaining mask layer is higher than the top surface of the ILD layer.

According to another aspect of the present invention, a semiconductor device is disclosed. The semiconductor device includes: a substrate; a metal gate on the substrate; an interlayer dielectric (ILD) layer around the metal gate; a mask layer on the metal gate and the ILD layer; and a void in the mask layer and above the metal gate.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1-5 illustrate a method for fabricating semiconductor device according to a preferred embodiment of the present invention.

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FIG. 6 illustrates a perspective view of a semiconductor device according to an embodiment of the present invention.

FIG. 7 illustrates a perspective view of a semiconductor device according to an embodiment of the present invention.

FIG. 8 illustrates a perspective view of a semiconductor device according to an embodiment of the present invention.

DETAILED DESCRIPTION

Referring to FIGS. 1-5, FIGS. 1-5 illustrate a method for fabricating semiconductor device according to a preferred embodiment of the present invention. As shown in FIG. 1, a substrate 12, such as a silicon substrate or silicon-on-insulator (SOI) substrate is provided, and a transistor region, such as a PMOS region or a NMOS region is defined on the substrate 12.

At least a first fin-shaped structure 14 and an insulating layer (not shown) are formed on the substrate 12, in which the bottom of the fin-shaped structure 14 is preferably enclosed by the insulating layer, such as silicon oxide to form a shallow trench isolation (STI). A plurality of metal gates 18 are formed on part of the fin-shaped structure 14. It should be noted that even though four metal gates are disclosed in this embodiment, the quantity of the metal gates is not limited to four, but could be any quantity depending on the demand of the product.

The formation of the fin-shaped structure 14 could be accomplished by first forming a patterned mask (now shown) on the substrate, 12, and an etching process is performed to transfer the pattern of the patterned mask to the substrate 12. Next, depending on the structural difference of a tri-gate transistor or dual-gate fin-shaped transistor being fabricated, the patterned mask could be stripped selectively or retained, and deposition, chemical mechanical polishing (CMP), and etching back processes are carried out to form an insulating layer surrounding the bottom of the fin-shaped structure 14. Alternatively, the formation of the fin-shaped structure 14 could also be accomplished by first forming a patterned hard mask (not shown) on the substrate 12, and then performing an epitaxial process on the exposed substrate 12 through the patterned hard mask to grow a semiconductor layer. This semiconductor layer could then be used as the corresponding fin-shaped structure 14. In another fashion, the patterned hard mask could be removed selectively or retained, and deposition, CMP, and then etching back could be used to form an insulating layer to surround the bottom of the fin-shaped structure 14. Moreover, if the substrate 12 were a SOI substrate, a patterned mask could be used to etch a semiconductor layer on the substrate until reaching a bottom oxide layer underneath the semiconductor layer to form the corresponding fin-shaped structure. If this means is chosen the aforementioned steps for fabricating the insulating layer could be eliminated.

The fabrication of the metal gates 18 could be accomplished by a gate first process, a high-k first approach from gate last process, or a high-k last approach from gate last process. Since this embodiment pertains to a high-k first approach, dummy gates (not shown) composed of high-k dielectric layer and polysilicon material could be first formed on the fin-shaped structure 14 and the insulating layer, and a spacer 24 is formed on the sidewall of the dummy gates. A source/drain region 26 and epitaxial layer (not shown) are then formed in the fin-shaped structure 14 and/or substrate 12 adjacent to two sides of the spacer 24, a contact etch stop layer (CESL) (not shown) is formed on the dummy gates, and an interlayer dielectric (ILD) layer 32 composed of tetraethyl orthosilicate (TEOS) is formed on the CESL.

Next, a replacement metal gate (RMG) process could be conducted to planarize part of the ILD layer **32** and CESL and then transforming the dummy gates into metal gates. The RMG process could be accomplished by first performing a selective dry etching or wet etching process, such as using etchants including ammonium hydroxide (NH₄OH) or tetramethylammonium hydroxide (TMAH) to remove the polysilicon layer from dummy gates for forming a recess (not shown) in the ILD layer **32**. Next, a conductive layer including at least a U-shaped work function metal layer **34** and a low resistance metal layer **36** is formed in the recess, and a planarizing process is conducted so that the surface of the U-shaped work function layer **34** and low resistance metal layer **36** is even with the surface of the ILD layer **32**.

In this embodiment, the work function metal layer **34** is formed for tuning the work function of the later formed metal gates to be appropriate in an NMOS or a PMOS. For an NMOS transistor, the work function metal layer **34** having a work function ranging between 3.9 eV and 4.3 eV may include titanium aluminide (TiAl), zirconium aluminide (ZrAl), tungsten aluminide (WAl), tantalum aluminide (TaAl), hafnium aluminide (HfAl), or titanium aluminum carbide (TiAlC), but it is not limited thereto. For a PMOS transistor, the work function metal layer **34** having a work function ranging between 4.8 eV and 5.2 eV may include titanium nitride (TiN), tantalum nitride (TaN), tantalum carbide (TaC), but it is not limited thereto. An optional barrier layer (not shown) could be formed between the work function metal layer **34** and the low resistance metal layer **36**, in which the material of the barrier layer may include titanium (Ti), titanium nitride (TiN), tantalum (Ta) or tantalum nitride (TaN). Furthermore, the material of the low-resistance metal layer **36** may include copper (Cu), aluminum (Al), tungsten (W), titanium aluminum (TiAl), cobalt tungsten phosphide (CoWP) or any combination thereof. Since the process of using RMG process to transform dummy gate into metal gate is well known to those skilled in the art, the details of which are not explained herein for the sake of brevity.

Part of the metal gates **18**, such as part of the work function metal layer **34** and low resistance metal layer **36** are then removed by etching process to form a recess **38** surrounded by the spacer **24** on each metal gate **18**.

Next, as shown in FIG. 2, a mask layer **40** is deposited on the ILD layer **32** and the metal gate **18** to fill the recesses **38**, in which the mask layer **40** is preferably composed of silicon nitride or silicon carbon nitride (SiCN), but not limited thereto. Preferably, as the mask layer **40** is covered on the ILD layer **32** and filled into each of the recesses **38**, a void **42** is formed in each recess **38** within the mask layer **40**. In this embodiment, the void **42** is preferably formed in the mask layer **40** above each metal gate **18** and lower than the top surface of the ILD layer **32**.

Next, as shown in FIG. 3, a planarizing process, such as a CMP process is conducted to remove part of the mask layer **40**. Preferably, the mask layer **40** is planarized without reaching the surface of the ILD layer **32** so that the top surface of the remaining mask layer **40** is still higher than the top surface of the ILD layer **32**.

Next, as shown in FIG. 4, a photo-etching process is conducted by using a patterned resist (not shown) as mask to etch part of the mask layer **40** and ILD layer **32** for forming a plurality of contact holes **44** adjacent to each metal gate **18**, in which the contact holes **44** preferably expose the source/drain region **26** in the substrate **12**.

Next, as shown in FIG. 5, a metal is filled into the contact holes **44**, and a planarizing process is conducted by removing part of the metal for forming a plurality of contact plugs **46**.

Since the fabrication of the contact plugs is well known to those skilled in the art, the details of which are not explained herein for the sake of brevity. This completes the fabrication of a semiconductor device according to a preferred embodiment of the present invention.

As the mask layer **40** is planarized without reaching the surface of the ILD layer **32** during the aforementioned planarizing process, the top surface of the remaining mask layer **40** would be substantially higher than the top surface of the ILD layer **32**. In other words, the top of each spacer **24** is protected by the mask layer **40** so that the top portion of the spacers **24** would not be damaged during the planarizing process. Consequently, as shown in FIG. 5, the distance between the contact plugs **46** and the top surface of ILD layer **32** to the metal gates **18** could be extended so that issues regarding contact plugs being too close to the metal gates thereby affecting performance of the device could be prevented.

Referring again to FIG. 5, which further illustrates a structural view of a semiconductor device according to an embodiment of the present invention. As shown in FIG. 5, the semiconductor device includes a substrate **12**, a plurality of metal gates **18** on the substrate **12**, a ILD layer **32** surrounding the metal gates **18**, a mask layer **40** on the metal gates **18** and ILD layer **32**, and a void **42** in the mask layer **40** and above each metal gate **18**.

In this embodiment, the void **42** is preferably lower than the top surface of the ILD layer **32**, but not limited thereto. Depending on the recipe or deposition condition of the mask layer **40**, the void **42** could also be formed in the mask layer **40** above the metal gate **18** while also higher than the top surface of the ILD layer **32**, which is also within the scope of the present invention. A plurality of contact plugs **46** are also disposed adjacent to the metal gates **18** in the mask layer **40** and ILD layer **32** while electrically connected to the source/drain region **26** in the substrate **12**.

Referring to FIG. 6, FIG. 6 illustrates a perspective view of a semiconductor device according to an embodiment of the present invention. As shown in FIG. 6, another ILD layer **48** could be formed on the mask layer **40** after the contact plugs **46** are formed, contact plugs **50** could be formed in the ILD layer **48** to electrically connect to the contact plugs **46**, and a contact plug **52** could be formed in the ILD layers **48** and **32** to electrically connect to the metal gate **18** directly. It should be noted that the void **42** would be filled during the formation of the contact plug **52** therefore would not be visible after the formation of the contact plug **52**.

Referring to FIG. 7, FIG. 7 illustrates a perspective view of a semiconductor device according to an embodiment of the present invention. As shown in FIG. 7, another ILD layer **48** could be formed on the mask layer **40** while no contact plugs are formed, and contact plugs **50** and **52** could then be formed in the ILD layer **48**, mask layer **40**, and ILD layer **32** to electrically connect to the source/drain region **26** and metal gate **18** respectively.

Referring to FIG. 8, FIG. 8 illustrates a perspective view of a semiconductor device according to an embodiment of the present invention. As shown in FIG. 8, contact plug **54** could be formed in the mask layer **40** to electrically connect to at least one metal gate **18** along with the contact plugs **46**. Next, another ILD layer **48** could be formed on the mask layer **40**, and contact plugs **50** and **52** could be formed in the ILD layer **48** to electrically connect to the contact plugs **46** and contact plug **54** respectively.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention.

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Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. A method for fabricating semiconductor device, comprising:

providing a substrate having a metal gate thereon and a first interlayer dielectric (ILD) layer around the metal gate; removing part of the metal gate to form a recess; and depositing a mask layer in the recess and on the first ILD layer while forming a void in the recess.

2. The method of claim 1, wherein the mask layer comprises silicon nitride or silicon carbon nitride.

3. The method of claim 1, further comprising forming a first contact plug in the mask layer and the first ILD layer.

4. The method of claim 3, wherein the top surfaces of the mask layer and the first contact plug are coplanar.

5. The method of claim 3, further comprising:
forming a second ILD layer on the mask layer and the first contact plug;

forming a second contact plug in the second ILD layer and contacting the first contact plug; and

forming a third contact plug in the mask layer and the second ILD layer and contacting the metal gate.

6. The method of claim 5, wherein the top surfaces of the second contact plug, the third contact plug, and the second ILD layer are coplanar.

7. The method of claim 1, further comprising:
forming a second ILD layer on the mask layer;
forming a first contact plug in the mask layer, the first ILD layer, and the second ILD layer; and

forming a second contact plug in the mask layer and the second ILD layer and contacting the metal gate.

8. The method of claim 7, wherein the top surfaces of the first contact plug, the second contact plug, and the second ILD layer are coplanar.

9. The method of claim 3, further comprising:
forming a second contact plug in the mask layer and contacting the metal gate;

forming a second ILD layer on the mask layer, the first contact plug, and the second contact plug;

forming a third contact plug in the second ILD layer and contacting the first contact plug; and

forming a fourth contact plug in the second ILD layer and contacting the second contact plug.

10. The method of claim 9, wherein the top surfaces of the first contact plug, the second contact plug, and the mask layer are coplanar.

11. The method of claim 9, wherein the top surfaces of the third contact plug, the fourth contact plug, and the second ILD layer are coplanar.

12. A semiconductor device, comprising:

a substrate;

a metal gate on the substrate;

a first interlayer dielectric (ILD) layer around the metal gate;

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a mask layer on the metal gate and the first ILD layer; and a void in the mask layer and above the metal gate.

13. The semiconductor device of claim 12, wherein the mask layer comprises silicon nitride or silicon carbon nitride.

14. The semiconductor device of claim 12, wherein the void is lower than the top surface of the first ILD layer.

15. The semiconductor device of claim 12, further comprising a first contact plug in the mask layer and the first ILD layer.

16. The semiconductor device of claim 15, wherein the top surfaces of the mask layer and the first contact plug are coplanar.

17. The semiconductor device of claim 15, further comprising:

a second ILD layer on the mask layer and the first contact plug;

a second contact plug in the second ILD layer and contacting the first contact plug; and

a third contact plug in the mask layer and the second ILD layer and contacting the metal gate.

18. The semiconductor device of claim 17, wherein the top surfaces of the second contact plug, the third contact plug, and the second ILD layer are coplanar.

19. The semiconductor device of claim 12, further comprising:

a second ILD layer on the mask layer;

a first contact plug in the mask layer, the first ILD layer, and the second ILD layer; and

a second contact plug in the mask layer and the second ILD layer and contacting the metal gate.

20. The semiconductor device of claim 19, wherein the top surfaces of the first contact plug, the second contact plug, and the second ILD layer are coplanar.

21. The semiconductor device of claim 15, further comprising:

a second contact plug in the mask layer and contacting the metal gate;

a second ILD layer on the mask layer, the first contact plug, and the second contact plug;

a third contact plug in the second ILD layer and contacting the first contact plug; and

a fourth contact plug in the second ILD layer and contacting the second contact plug.

22. The semiconductor device of claim 21, wherein the top surfaces of the first contact plug, the second contact plug, and the mask layer are coplanar.

23. The semiconductor device of claim 21, wherein the top surfaces of the third contact plug, the fourth contact plug, and the second ILD layer are coplanar.

24. The semiconductor device of claim 12, wherein the top surface of the mask layer is higher than the top surface of the metal gate.

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